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AIRCRAFT PROGRAM FOR TARGET, BACKGROUND, AND SKY RADIANCE MEASUREMENTS

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AIR FORCE SYSTEMS COMMAND
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A review of PhotoMetrics' field and data reduction work for the Air Force Geophysics Laboratory in the DNA-sponsored nuclear effects simulations program and the ARPA-sponsored targets and backgrounds measurements program during the period April 1978-April 1979 is presented. Data flights of USAF NKC-135 53120 on which PhotoMetrics operated radiometric → over

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20. Abstract

instruments, the design, fabrication and application of an optical co-aligner for very narrow-angle aircraft instruments are documented, and modifications to an ISIT vidicon camera for auroral imaging are reviewed.

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FOREWORD

This report reviews PhotoMetrics' contributions to the DNA-sponsored nuclear effects simulations program, and the ARPA-sponsored target and background measurements program. It includes a summary of PhotoMetrics' participation in the aircraft field program, a review of the design, fabrication and field test of an optical co-alignment system, and modifications to the auroral vidicon camera. The work presented here is a continuation of efforts begun under earlier DNA and ARPA contracts.

PhotoMetrics' work was directed by I. L. Kofsky and R. B. Sluder, and the field measurements were conducted by R. B. Sluder and D. P. Villanucci. The alignment system was designed by W. S. Andrus, with mechanical engineering assistance provided by J. Costa. We wish to thank T. P. Markham, B. P. Sandford, E. R. Huppi, A. T. Stair, Jr., and their associates of AFGL's OPR branch for their support and encouragement.

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INTRODUCTION AND SUMMARY

The aircraft missions reported here were performed as part of AFGL's ongoing measurements program applying the USAF data platform NKC-135, S/N 55-3120. One purpose of this program is to obtain infrared spectral signatures and spatial brightness distributions of aircraft targets, and of earth surface, sky and meteorological cloud backgrounds. Another goal is the measurement of the intensity of infrared emissions in aurora, and in particular to assess the temporal and spatial correlation between auroral energy inputs and infrared emissions. A list of the data flights in which PhotoMetrics participated in the reporting period is in Table 1.

Since the target measurements are made in a partially-absorbing atmosphere on sources of variable geometry, the apparent intensity depends on target range and aspect angle. PhotoMetrics' principal contribution to the signature program was to determine the target's range and orientation relative to the data platform. In the auroral series, flights 820 to 827 and 906 to 911, we provided information about the spatial and temporal radiance of the visible aurora that indicates particle energy input into the upper atmosphere.

The instrumentation developed for both programs and operated during the flights reported here, and the data reduction methods employed, are substantially the same as those used previously, as reported in References 1 and 2.

A secondary goal of the auroral flights was simultaneous measurement of auroral radiance distributions by the DMSP Block 5D F1, polar oribiting satellite and by photometers onboard the aircraft. During missions 820, 821, 824 and 826 auroral intensities IBC I to II+ were measured by aircraft and satellite photometers, which should result in a calibration of the satellite sensor against particle-induced air fluorescence. Results of this co-ordinated experiment and other measurements on aurora will appear elsewhere.

Table 1. Log of Flights of NKC-135, S/N 55-3120
April 1978 - May 1979 U.T.

Identification	Date	Location	Take-off	Landing
807	29 Apr 78	Pease AFB-Nellis AFB	1534	2040
808	2 May	Nellis-Nellis	1731	2359
809	8 May	Nellis-Nellis	1223	1640
810	9 May	Nellis-Nellis	1327	1927
811	10 May	Nellis-Nellis	1327	2027
Ferry	13 May	Nellis-Pt. Mugu NAS	1847	2014
812	16 May	Mugu-Mugu	1122	1622
813	18 May	Mugu-Mugu	1514	1944
814	19 May	Mugu-Pease	1505	2025
815	22 June	Pease-Barksdale AFB	0907	1419
816	23 June	Barksdale-Barksdale	1157	1755
817	24 June	Barksdale-McClellan AFB	2315	0517
818	28 June	McClellan-McClellan	2250	0433
819	8 July	Pease-Pease	1330	1635
Ferry	25 Aug	Pease-Eielson AFB	2142	0505
820	27 Aug	Eielson-Eielson	0728	1224
821	28 Aug	Eielson-Eielson	0710	1215
822	29 Aug	Eielson-Eielson	0425	1132
823	31 Aug	Eielson-Eielson	1446	2027
824	2 Sep	Eielson-Eielson	0739	1331
825	4 Sep	Eielson-Eielson	1405	1908
826	7 Sep	Eielson-Eielson	0718	1214
827	8 Sep	Eielson-Pease	1502	2143
Ferry	20 Sep	Pease-Moffett NAS	1500	2115
828	21 Sep	Moffett-Nellis	1625	2310
829	25 Sep	Nellis-Edwards	1715	2140
		Edwards-Nellis	2343	0020
830	28 Sep	Nellis-Nellis	1402	1806
831	28 Sep	Nellis-Nellis	2111	2207
832	30 Sep	Nellis-Pease	1520	1952
Ferry	23 Jan 79	Pease-Edwards AFB	1606	2206
901	26 Jan	Edwards-Edwards	1530	2145
902	27 Jan	Edwards-Edwards	1707	2105
Ferry	20 Feb	Pease-Wright Patterson AFB	1525	1725
Ferry	21 Feb	Wright-Patterson-Edwards	1256	1726
903	22 Feb	Edwards-Edwards	1630	2345
904	23 Feb	Edwards-McClellan	2015	0100
905	26 Feb	McClellan-Offutt AFB	1246	1811
Ferry	27 Feb	Offutt-Pease	1719	2009
906	21 Apr	Pease-Pease	0135	0750
907	23 Apr	Pease-Pease	0121	0750
908	25 Apr	Pease-Pease	0020	0806
909	26 Apr	Pease-Pease	2312	0612
910	30 Apr	Pease-Pease	0505	1200
911	1 May	Pease-Pease	2230	0550

Section II of this report documents the design, fabrication and initial field application of an optical co-alignment system, used to boresight an infrared radiometer, a visible wavelength photometer and the vidicon camera. Results of laboratory tests of precision and operation under field conditions are reviewed. Also included are schematic diagrams and photographs of the aligner and its operation.

Section III describes recent modifications to the auroral vidicon camera (Aircraft System E-209) which improve its effectiveness for determining visible auroral brightness distributions. Photographs of typical video frames recorded during the April 1979 flight series are presented.

Range and aspect for various aircraft targets were calculated from measurements of approximately 325 photographic frames recorded during these and earlier flight series. The computer program (Ref 1) that performs these calculations was modified to present the data in the frame-of-reference of the target. The tabulated information includes the slant range between the target and infrared spectroradiometers, the location of the infrared sensors in cartesian coordinates, and roll, pitch and yaw angles of the observation line-of-sight. Photographic prints of aircraft targets and backgrounds, prepared from the original 16 mm films, and the range/aspect information were transmitted directly to AFGL personnel.

SECTION II

FIELD CO-ALIGNER FOR AIRCRAFT OPTICAL INSTRUMENTS

BACKGROUND

To measure the short wavelength-infrared outputs from known particle energy inputs into high altitude air, coaligned photometers and radiometers and the low-light-level video camera (Section III) will be installed in AFGL's NKC-135 aircraft S/N 55-3120 (as further described in Appendix I of Ref 3). In order to minimize systematic error in the measured infrared-visible spatial and temporal correlations, the narrow field photometers and radiometers must point to the same region of the sky within a small fraction of their angular field width, and the location of this direction in the camera field must be known to similar accuracy. A total alignment error of less than 3 arc min (0.05^{o}) was adopted as the design goal.

Since the radiometer instrument is sealed in an enclosure, the alignment must be performed by instruments directed through its viewing port and thus located atop the aircraft. Note that the radiometer and photometer are tilted $\sim 15^{o}$ forward of the static aircraft vertical so that they (very closely) point up the geomagnetic field lines when the aircraft is in flight southward along the meridian at auroral latitudes. The coalignment of one of the photometer-radiometer pairs that has so far been installed is described below.

ALIGNER DESIGN

The alignment procedure is required to meet the following constraints:

1. Attachment of the aligning instruments to the aircraft must be sufficiently rigid to meet the 3 arc min design goal.
2. The alignment procedure should require less than one hour, except in cases where the aircraft instruments

need major adjustment. Highly specialized skills should not be required; that is, alignment should be achieved in the field by the technical crew.

3. The equipment should be light and compact enough to be carried to the top of the aircraft by one or two workers, and simple enough to comply with Item 2 above.

4. Support requirements should be limited to normal aircraft electrical power and intercom.

5. Ambient darkness should not be necessary, that is, the alignment should be performable in an aircraft hangar or, preferably, outdoors during the day.

The most accurate alignment would be independent of the rigidity of mechanical components. A purely optical system, using an autocollimator referencing to a fixed mirror, was considered in some detail. We concluded that this type of system was incompatible with constraints No. 2 and No. 5, as the series of optical alignments required would be difficult and time-consuming, particularly in a lighted environment. The increased accuracy would in any event have been illusory, as the optical axes of the photometer and radiometer themselves probably cannot be defined with better than 3 arc min accuracy.

Design of an optical system including a mechanically rigid element required special consideration of constraints No. 1 and No. 3. A rigid element was needed which was light enough to be carried to the top of the aircraft and to be attached there with sufficient stability for the alignment. It should be noted that there are few rigidly fixed points on the top surface available to anchor the aligner device. The aircraft's outer skin is quite flexible, and of course no mounting holes could be drilled into the more rigid frame structure.

A design conforming to all of these constraints was developed using a bonded, honeycomb sandwich panel (Hexcel Corp., Dublin, CA)

to establish a reference plane. The panel is 4 in thick, 60 in long, and 14 in wide, and although it weighs less than 15 lb is rigid enough (according to calculation) to flex less than 1 arc min under the weight of the alignment instrument it supports. Flat aluminum pads ($2\frac{1}{2}$ or $14\frac{1}{2} \times 6\frac{1}{2} \times \frac{1}{4}$ in) attached to the panel, adjusted so that their top faces are parallel as determined by an optical test described below, define the reference plane. The aircraft instruments are required to point at the same fixed angle relative to this reference plane. A $3\frac{1}{2}$ in aperture telescope/collimator (Questar Corp., New Hope, PA) was used to set the normal to the instruments.

The radiometer pointing direction was selected as the reference direction. That is, the photometer was coaligned to point in a direction parallel to the radiometer's optic axis, and the projection of this direction into the camera field was determined. A flat reference mirror mount was aligned (in the laboratory, by another group) normal to the radiometer's axis. To determine direction of the photometer's optic axis, the field stop of the photometer was illuminated and viewed by the autocollimator through its objective lens. To locate the video camera, the parallel autocollimator beam was projected onto its focal plane by its objective lens, so that the position of the beam could be viewed on the video monitor simultaneously with the camera's reticle.

The measurements of the three instrument axes were made with the autocollimator on the rigid optical bench or platform, which is shown schematically in Figure 1. Circular clearance holes for the optical beam were cut through the panel at the instrument positions. A view of the bench on top of the aircraft is in Figure 2.

MOUNTING ON THE AIRCRAFT

The assembly rests on the aircraft on three legs of adjustable length. Two legs, near the aft part of the bench, support the ends of a horizontal plate to which the panel is fastened (Fig 3). The third leg (Fig 4) is placed at a point near the center of a similar horizontal

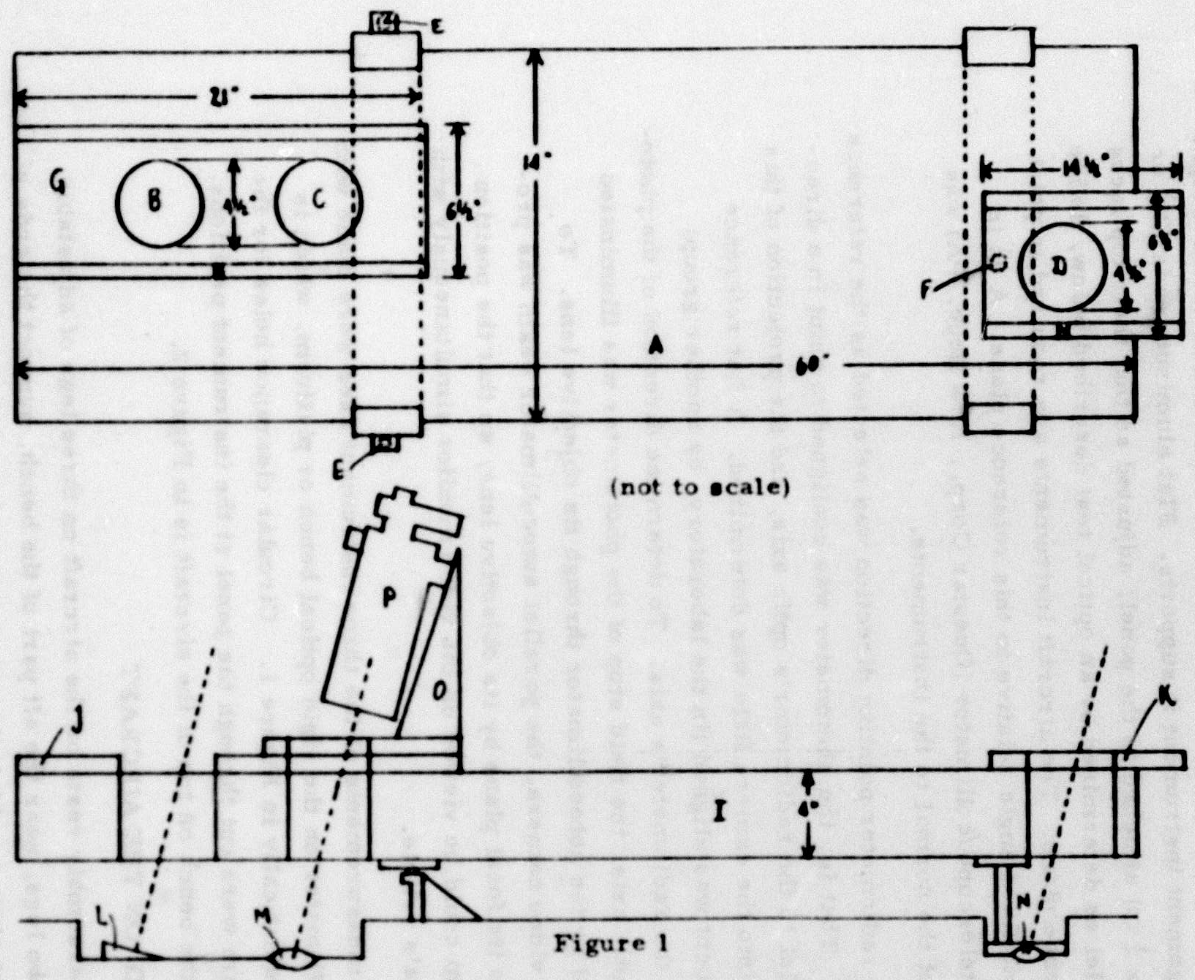

Figure 1

Schematic drawing of the aligner. A) Plan view of bonded honeycomb sandwich panel; B) radiometer opening; C) photometer opening; D) video camera opening; E) aft legs; F) forward leg; G) pad; H) orientation rails. I) Side view of panels; J) aft pad; K) forward pad; L) radiometer reference mirror; M) photometer lens; N) camera lens; O) sled; P) autocollimator.

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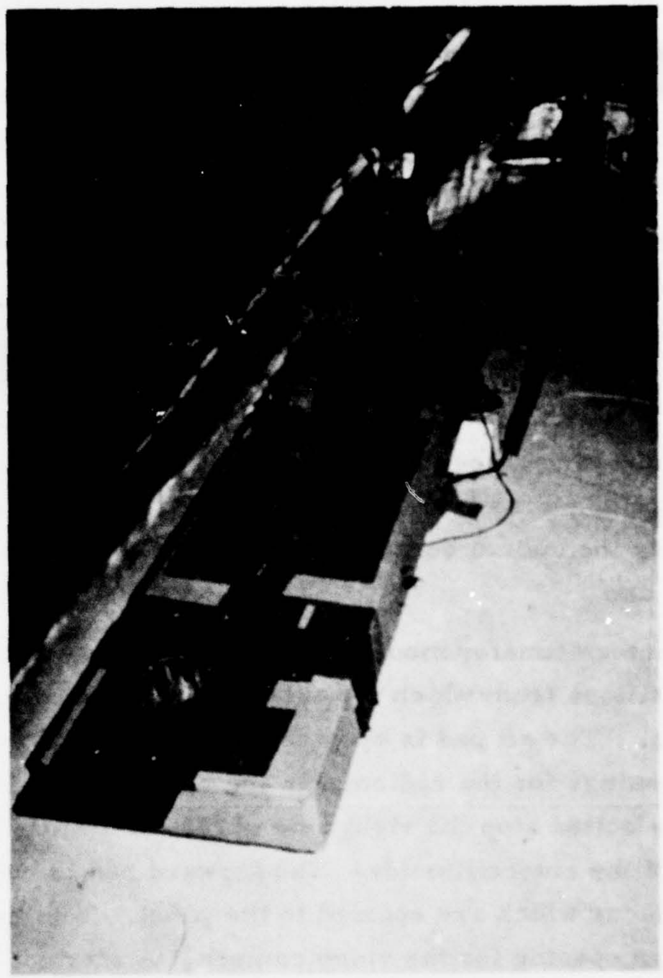


Figure 2. The alignment system as seen looking aft on the aircraft. The autocollimator is on its sled in position to illuminate the photometer. In the foreground is the $4\frac{1}{2}$ inch diameter opening for locating the beam direction in the low light level video camera.

member supporting the forward end of the panel. This adjustable three point suspension allows precise orientation of the plane defined by the two pads. The forward leg rests in a recess in a specially-fabricated circular aluminum ring placed in the camera's narrow-field viewing window. During alignment, horizontal set screws in the ring are butted against the sides of the window recess, keeping the ring fixed in position.

The aft legs rest in recesses in a mounting fixture which rests on top of the aircraft between the 12 inch diameter radiometer/photometer window and an aluminum aerodynamic spoiler (Fig 5). This is an area of increased rigidity since the spoiler and window are attached to the airframe in this region. Pins in the mounting fixture are inserted into existing holes in the spoiler aft plate to prevent motion of the aft mounting points during alignment. This system for mounting and orienting the optical bench has been found to be both stable and efficient in use.

The autocollimator mounting pads (Fig 6)are attached to the panel in positions from which the autocollimator can illuminate the instruments. The aft pad is epoxied to the panel and has two $4\frac{1}{2}$ inch circular openings for the radiometer and photometer. A straight steel rail is bolted atop the right side of the pad to provide left-right alignment of the autocollimator. The forward pad is bolted to two mounting places which are epoxied to the panel. This pad has a $4\frac{1}{2}$ inch circular opening for the video camera. A straight steel rail is bolted atop the right side of the pad for left-right alignment. The clearance holes are large enough to permit left-right motion of the rail on the pad and of the pad on its mounting plates. The pad can also be tilted by placement of shims between pad and mounting plate.

The autocollimator is mounted on an aluminum sled (see Fig's 5 and 6) that has flat runners to rest on the pads and against the steel rails, thus defining its orientation. Magnets are epoxied into the

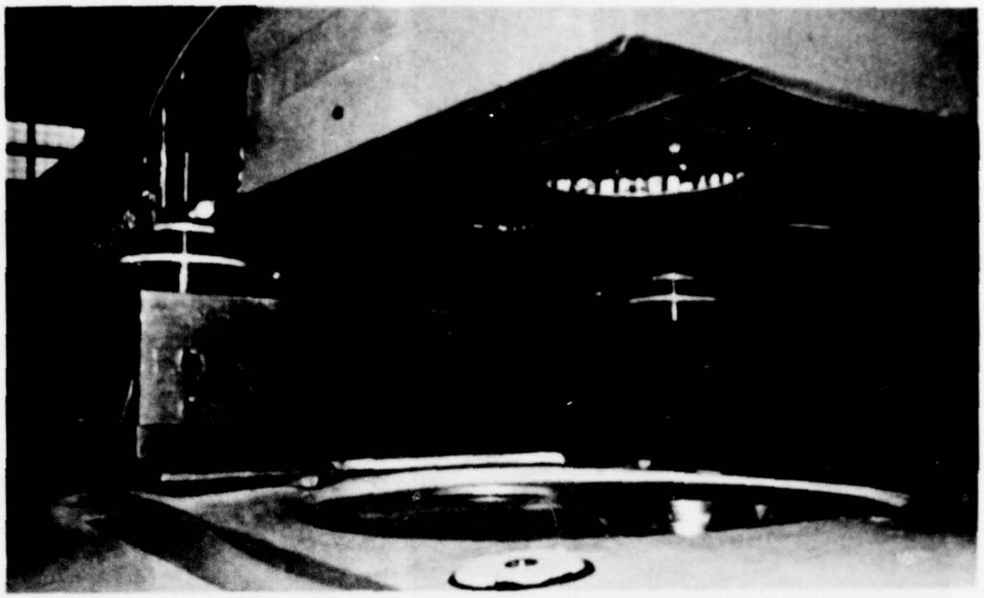
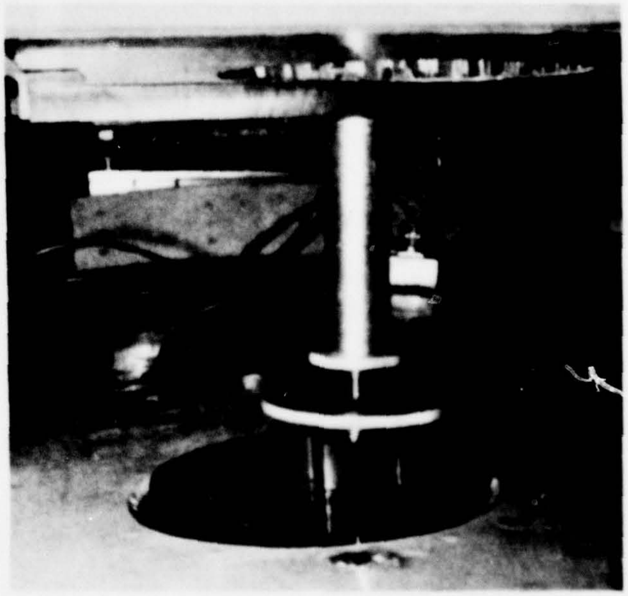


Figure 3. The underside of the panel, showing its aft legs resting on a fixture supported by the aircraft spoiler. The radiometer/photometer window is in the lower foreground.

Figure 4.

The aligner's forward leg resting in an aluminum ring located by the camera window recess. The aft legs, visible in the background, complete the three point suspension. The aerodynamic spoiler is the curved plate beneath the aft legs.



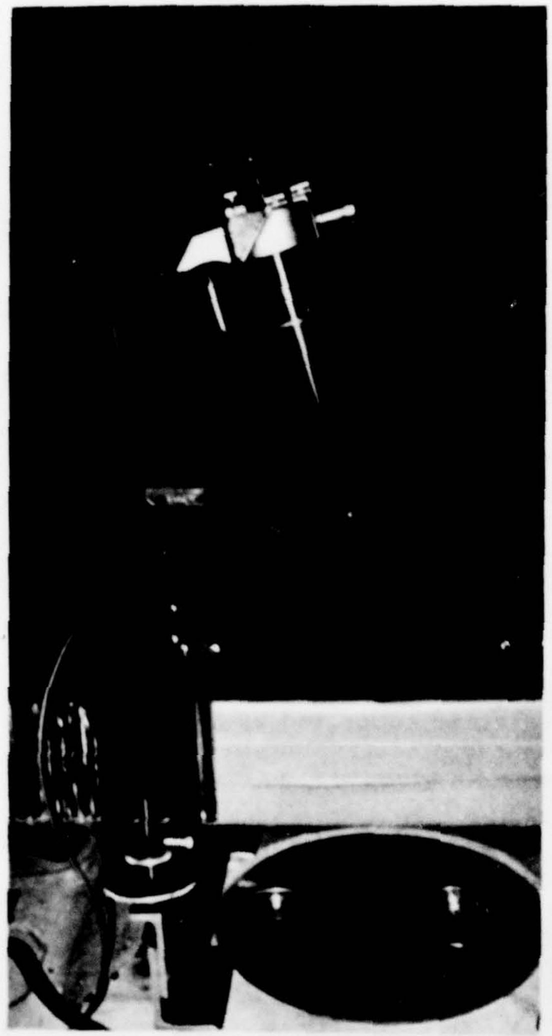


Figure 5.

The aft end of the panel, showing the mounting fixture and a side view of the aircraft's aerodynamic spoiler. The autocollimator on its sled is in position to illuminate the radiometer reference mirror.

Figure 6.

Top view of the sled, illustrating how the rail sets its left-right alignment.

runner to aid in keeping it flush against the steel rail. The sled can hold the autocollimator pointing either nominally horizontally or at a nominal 15° to the vertical.

ALIGNMENT OF THE BENCH

The horizontal position is used for field check of the alignment of the optical bench. The test is performed atop the aircraft with the optical bench in its standard measuring position as described above. The bench is oriented so that the aft pad is level to a few arc min in the left-right direction, as determined by a spirit level. A flat mirror is mounted on a tripod resting on the fuselage about 1 meter aft of the bench. The sled is placed on the aft observing pad flush against the steel rail, and the return image from the mirror acquired. When the return cross hair image coincides with the original cross hairs, the mirror plane is normal to the autocollimator axis.

Next, without disturbing the mirror, the sled and autocollimator are moved to the forward pad and the sled placed flush against the steel rail. If the return image coincides with the cross hairs, the autocollimator axis is normal to the mirror plane and thus parallel to its orientation on the aft pad. If not, the forward pad is reoriented until this condition is achieved and the forward pad is level in the left-right direction.

With the bench alignment established, the autocollimator is remounted in its near-vertical orientation on the sled. The sled is moved to the aft opening on the aft pad and the autocollimator cross-hair return image from the radiometer reference mirror is acquired. The bench is tilted, using its three adjustable legs, until the return image coincides with the cross hairs. The bench is locked in this position for the remainder of the instrument coalignment procedure.

ALIGNMENT OF THE PHOTOMETER AND VIDEO CAMERA

The autocollimator and sled are moved to the forward opening of the aft pad and the field stop opening of the photometer is illuminated through the autocollimator and the photometer objective lens. The

image of the opening is moved by means of a mirror in the photometer optics until it is centered on the autocollimator cross hairs. When this condition is achieved, the radiometer and photometer are co-aligned.

The autocollimator and sled are then moved to the forward pad and the autocollimator beam is then made to illuminate the video camera. The position of the autocollimator cross hair image in the television picture marks the position of the photometer/radiometer field (Fig 7). The pointing mirrors in the camera are adjusted to obtain the required relative positioning of the images of the autocollimator cross hairs and camera focal-plane reticle.

When coalignment has been completed, the sled is returned to the aft opening in the aft pad. Coincidence of the return image from the radiometer reference mirror with the cross hairs verifies that the optical bench has not been moved during the procedure.

FIELD ALIGNMENT

Coalignment was performed in the period 17 April - 02 May 1979 in a hangar at Pease AFB, NH. The photometer was found to drift as much as 20 arc min after the earliest $\sim$ 6 hr auroral flight missions. In comparison, only very small changes in pointing of the camera with respect to the radiometer (the reference) were detectable. The misalignment of the photometer (a new instrument) was identified as being caused principally by strains introduced by its cover screws and errors in the servomechanism that controls its internal mirror. After the photometer group had taken steps to correct these difficulties, post-flight alignment offset decreased to $\lesssim$ 3 arc min.

Repeated tests on the radiometer alone indicated 1) that the alignment-assisting mirror whose normal is parallel to the optic axis could be removed and replaced reproducibly within 2-3 arc min; and 2) the complete instrument, replaced in its mounting position, reproduced within 5-7 arc min when care was taken to stress the retaining straps uniformly.

Figure 7. Television monitor image, showing the camera focal plane reticle (bright vertical lines) and aligned autocollimator reticle (dark cross on small circular gray background). The hangar ceiling's image is in the background.

CONCLUSIONS

The aligner thus served to assess the inherent mechanical stability of the photometer's, radiometer's, and video camera's optical systems. In addition, the autocollimator telescope turned out to be useful in adjusting the focus of the photometer, which is set at infinity.

The coalignment system was found to meet all of the criteria for use specified above. The feasibility of rapidly aligning the aircraft instruments was demonstrated. Stability of the optical bench and of its attachment to the aircraft was sufficient to allow the design goal of < 3 arc min precision to be met. As experience was acquired during the flight series, the complete co-alignment procedure, including transporting and installing the equipment on the aircraft, could be accomplished in about 3/4 hour. Ambient light inside the hangar did not interfere with the reading of the autocollimator (no test in full outdoors daylight was made).

SECTION III

MODIFICATIONS TO THE AURORAL VIDICON SYSTEM

Due to funding constraints, some features in the original design of the dual-field television system were not implemented in the first phase of its construction and field testing. These include wavelength-isolating filters with automatic advance, manual control of vidicon gain, and an illuminated reticle for the narrow field optics. Section III of Ref 1 contains a detailed description of the system design and a review of its performance in producing images of weak auroral brightness distributions.

FILTERS

Interference filters for two wavelengths were specified and procured from Barr Associates, Concord, MA. These filters isolate the relatively long-lived $O\,^1S - ^1D$ (5577 Å) and $O\,^1D - ^3P$ (6300 Å) atomic emissions from the prompt fluorescence of molecular nitrogen at shorter and longer wavelengths. The prompt emissions toward the blue, principally N_2^+ First Negative bands, are isolated by a broad band Schott glass filter. Critical characteristics of the filters are summarized in Table 2. Examples of auroral imagery recorded during the April 1979 flights both unfiltered and with each of the filters in position,are shown in Figures 8 and 9.

Table 2. Summary of Filter Characteristics

Center λ, Å	Emission Feature	Filter Type	FWHM, Å	Transmission (Wavelength, Å)
5584	$O\,^1S - ^1D$	Interference	20	0.68 (5577)
6307	$O\,^1D - ^3P$	Interference	23	0.81 (6300)
4000	Molecular nitrogen	Dye, Schott BG-12	1450	0.85 (3914 & 4278)

GAIN CONTROL

The ISIT vidicon camera as delivered provides both automatic operation, in which the lens iris, intensifier high-voltage and video signal processing are controlled continuously as a function of input image-plane irradiance; and a manual mode, in which the above controls are disabled, the intensifier gain is fixed, and the iris is manually set. To achieve additional control of the image signal, we remotely-located the intensifier gain adjustment to the console. When the camera is in manual mode a ten-position switch selects the high-voltage applied to the first intensifier section of the vidicon tube, thus setting its gain. A second output from the switch provides a 4-bit BCD signal of gain selected, used as the input to the digital video display described below.

VIDEO DISPLAY

To facilitate data reduction and review of the video imagery, nine digits of Universal Time (down to millisec precision) and single digit codes for gain selected and filter position were added to the video signal (shown at the bottom left of each image in Fig's 8 and 9). (Time code is normally recorded on one of the audio channels of the magnetic tape, and is decoded and displayed on a separate time code reader.) A Datum Time Code Translater, Model 9200 with Video Inserter Option (Datum, Inc., Anaheim, CA) accepts the aircraft's master IRIG-B time code, and through its video amplifier produces a composite data-plus-time code signal, displaying hours, minutes, seconds and milliseconds directly on the video monitor and recording this information on magnetic tape. Thus, each frame of the 30 frame/sec video image is identified uniquely. Three additional digit display inputs, accessible by means of a rear panel connector, accept the BCD format produced by the gain select switch and filter position sensors. Although not implemented to date, the third digit will indicate whether automatic or manual gain is selected.

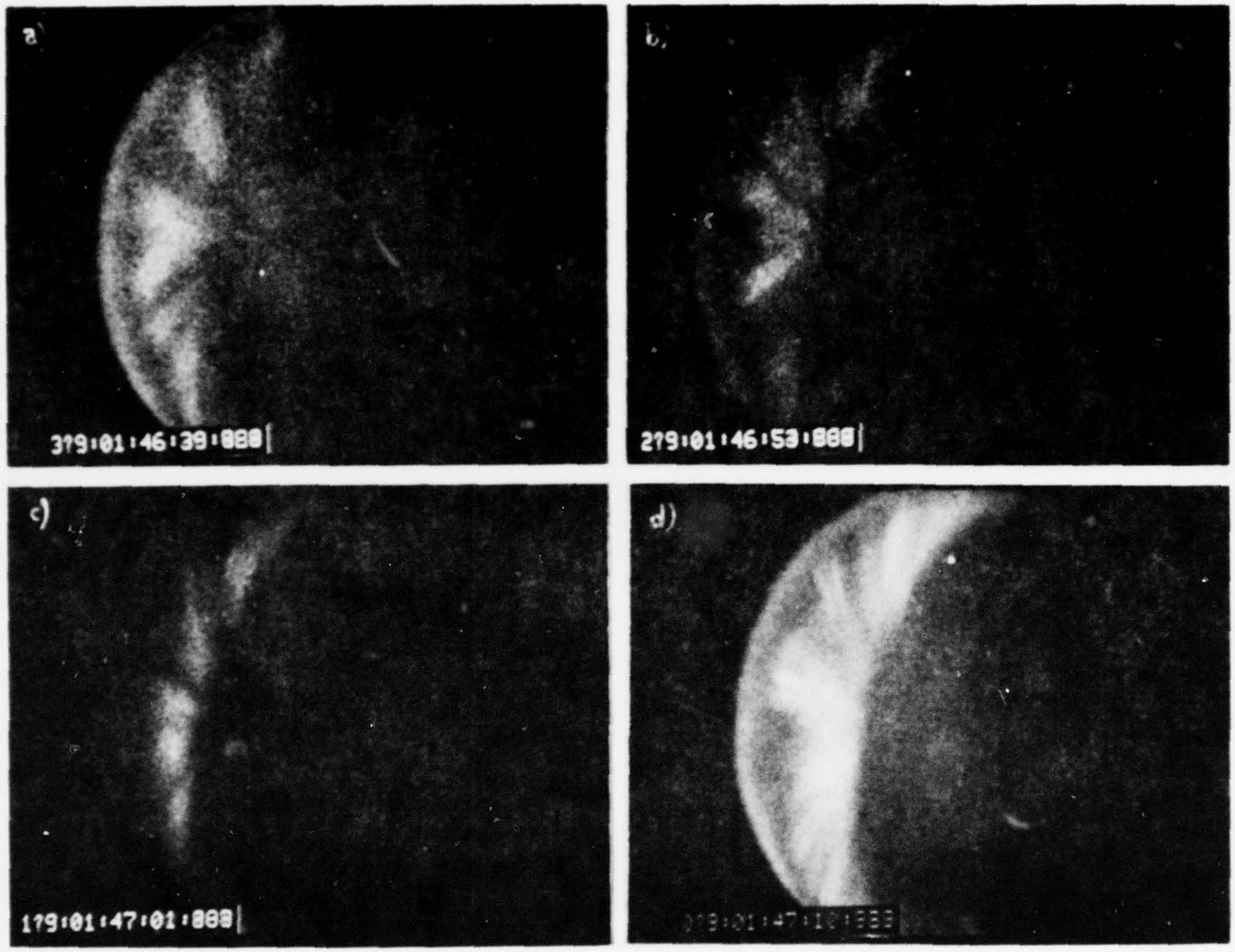


Figure 8. Auroral images recorded with a) the OI 5577 Å filter (code 3, first digit), b) the N_2 - N_2^+ short-wavelength bands filter (code 2), c) the OI 6300 Å filter (code 1), and d) no filter, S-20 spectral response of the cathode (code 0). $\frac{1}{2}$ sec integrating time, all-sky field.

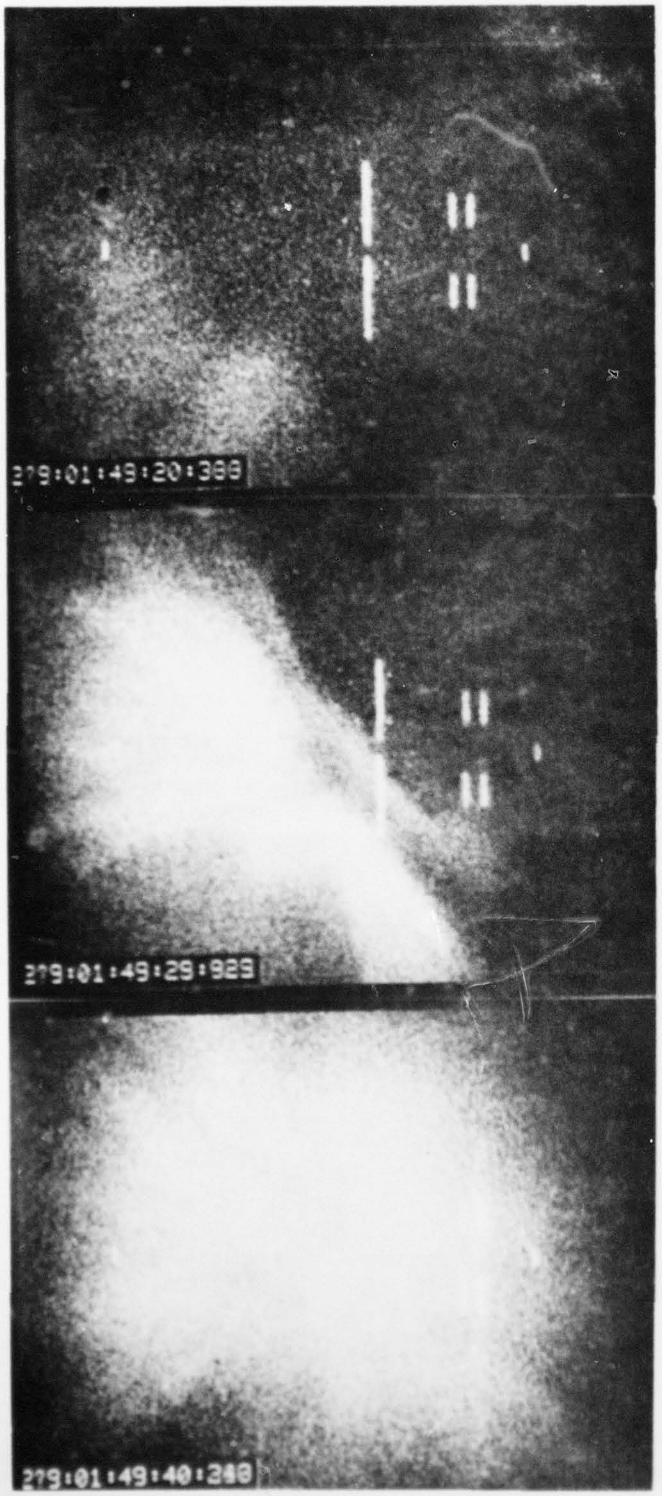


Figure 9.

Video images through the N_2/N_2^+ filter showing the camera's focal-plane reticle under three conditions of mean image irradiance.

ILLUMINATED RETICLE

A reticle placed in the focal plane of the objective lens of the narrow field optics locates the 0.4 deg radiometer field within the television's 15 x 20 deg field. The reticle pattern, visible in Fig 9, is etched in a glass substrate and filled with a white pigment to produce a bright-line image when edge-lighted. A rheostat controls the voltage to four small tungsten bulbs to enable the pattern intensity to be varied as the image brightness changes. The two pairs of longer vertical lines mark the horizontal location of the radiometer field, and the short bars at left and right indicate the vertical location. These lines were located purposely away from the radiometer's field to avoid interference with the data signal.

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